Noise reduction for the infrared beamline at the Advanced Light Source

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ABSTRACT

Significant reductions in the noise of the infrared light have been made at Beamline 1.4.3 infrared source at the Advanced Light Source (ALS). The primary source of vibrational noise has been identified as the water system for the storage ring RF system, which is located near the beamline. Modifications to this system have reduced the noise by an order of magnitude. The dominant source of higher frequency noise has been identified as phase noise in the RF master oscillator driving synchrotron oscillations of the beam. We present measurements of the effect of the electron beam motion in a Fourier transform interferometer (FTIR) detector and a discussion of the coupling mechanism to the beam.

Keywords: infrared, synchrotron radiation, electron storage rings

1. INTRODUCTION

Interest in infrared (IR) synchrotron radiation has grown dramatically in the past few years. However, synchrotron radiation IR sources have proven to be very sensitive to both beam motion and mechanical motion of the endstation.[1–3] The beam motion can result from a combination of self-excited and driven motion, ranging in frequency from a few hertz to hundreds of megahertz. IR beamline 1.4.3 at the Advanced Light Source (ALS) located at Lawrence Berkeley National Laboratory is no exception to these problems.

Over the past year, we have made an effort to identify and resolve noise issues in the beamline as well as understand the mechanisms for observing the noise. Our strategy has been to remove or reduce the noise source as much as possible and to eventually reduce the remaining noise to acceptable levels using active feedback. We divide the noise into two categories: 1) low frequency noise of less than 1 kHz which couples to the photon beam either through the beam or mechanical vibrations of the beamline and 2) high frequency noise which couples via an electron beam resonance. This paper summarizes our progress to date.

Section 2 gives a brief description of the beamline. Section 3 presents a summary of our efforts at locating and reducing low frequency noise. Section 4 describes the improvments we have made in reducing high frequency noise. In particular, we have made a detailed study of beam motion excited by phase noise in the master oscillator (MO) of the RF system since this was determined to be one of the dominant noise sources.

2. MEASUREMENT SETUP

The ALS is a 1.5–1.9 GeV electron storage ring optimized for producing high brightness synchrotron radiation. The synchrotron light is collected from the 1.4 bending magnet with source parameters listed in Table 1.

The light passes through a 10mrad vertical and 40mrad horizontal opening, as schematically drawn in Figure 1. This light is deflected vertically by 0.5 meter, then is refocused outside the shield wall by an ellipsoidal mirror, M2. A “switchyard” then contains a series of optics to collimate the IR beam and distribute the beam to one of three end stations.

BL 1.4.3 directs the collimated synchrotron light into a Nicolet Magna 760 FTIR bench. The modulated light is then passed through a Nic-Plan IR microscope that can perform both transmission and reflection measurements. BL 1.4.2 uses the synchrotron light for the input of a Bruker IFS 66v/S vacuum FTIR spectrometer. This IFS 66v/S instrument has a wide spectral range, 50 cm-1 to 25,000 cm-1, and it has step-scan capabilities in addition to rapid-scan to enable fast timing measurements. BL 1.4.1 uses the UV part of the spectrum from the 1.4 front end to do photoluminescence and related studies up to 6eV.

To study the spectrum of noise in the FTIR, we fixed the moving mirror in the interferometer and recorded the output of the detector on a spectrum analyzer. All of the spectra shown in this paper were made in this way.

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Parameter	Description	Value
E	Beam energy	1.5–1.9 GeV
I	nominal current range	100–400 mA
ϵ_x, y	x,y emittance@1.9 GeV	6,0.06 nm-rad
β_x, y	x,y beta functions	0.45,19.0 m
α_x, y	x,y alpha functions	0.43,-7.7
η_x	dispersion function	4.18 cm
$\eta_x^{'}$	dispersion slope	0.13

Table 1. ALS IR source parameters.

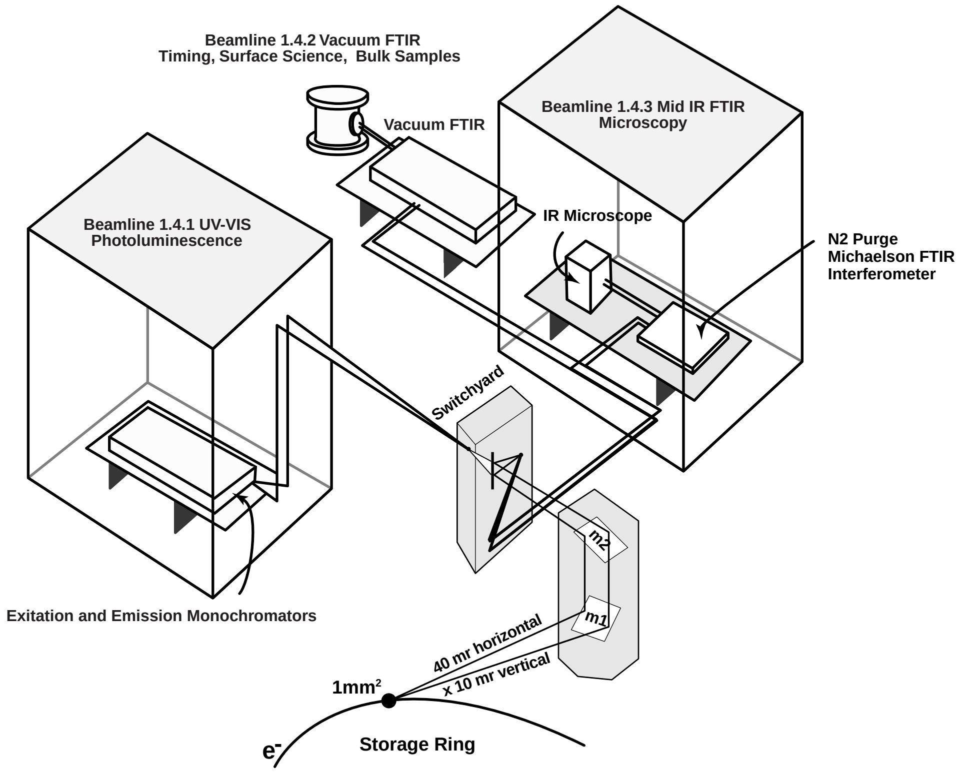

Figure 1. Schematic layout of the ALS infrared beamline.

3. LOW FREQUENCY MEASUREMENTS

At the initial commissioning of the IR beamline, we immediately observed low frequency noise. Although the beam noise manifests itself in the FTIR spectra, our technique for characterizing the frequency spectra of the noise is to observe the FTIR signal on a spectrum analyzer. One of the primary noise sources was quickly identified as the pumps for the RF water system, which unfortunately was located on the inner storage ring wall across from the IR beamline. The water system consists of 4 pumps mounted to the floor with associated plumbing mounted to the inner storage ring wall. Noise spectra with the water pumps turned on and off are shown in Fig. 2. Several modifications were made to the RF water system to reduce the noise such as reducing the motor impellers by 1 inch and installing variable frequency drives were installed on each of the four motors.

To mechanically isolate the beamline, the support for the M1/M2 mirrors was remounted from the upper concrete slab floor to the lower thicker slab which is considerably more stable. In addition, the “switchyard” was remounted from the outer storage ring wall to a separate mount on the lower slab of the floor. Thermal effects were reduced by removing the finger mask for M1 and M1 from the global LCW cooling system and installing a local chiller.

The net effect of these changes of the FTIR spectra is shown in Fig. 3. The upper trace shows the noise measured

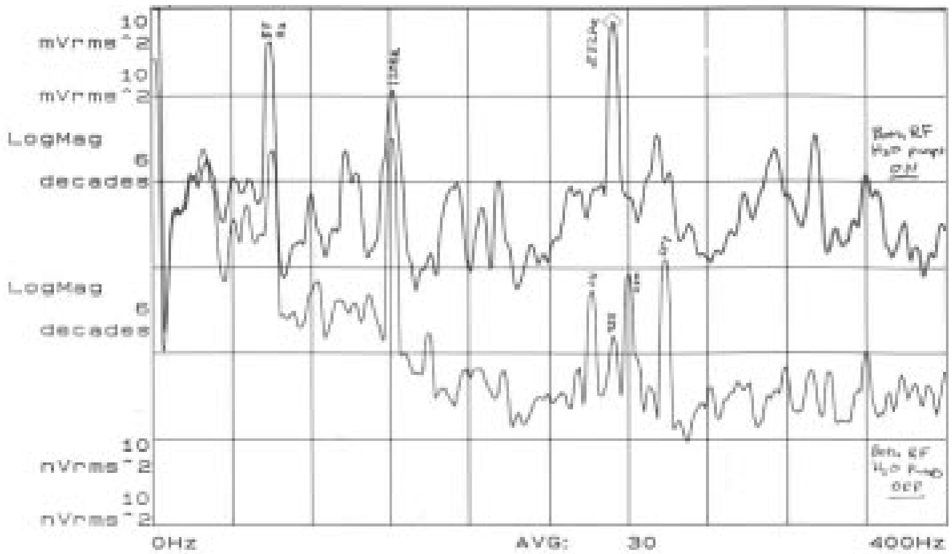

Figure 2. Noise reduction with RF water system pumps off.

in October 1997 shortly after first light to the beamline. The noise has a 0.5% RMS deviation from 100% throughout the mid-IR region. The lower two curves show the improvements of reducing the low frequency noise with an RMS noise of 0.05%. Note that the decrease in noise excludes the increased noise observed at the low end of the FTIR spectrum. This noise corresponds to a real frequency of 4–8 kHz and its source and reduction is discussed explicitly in the next section.

4. HIGH FREQUENCY MEASUREMENTS

To study the spectrum of noise in the FTIR, we fixed the moving mirror in the interferometer and recorded the output of the detector on a spectrum analyzer. An example of this measurement is shown in Fig. 4, which shows a noise peak at about 3.7 kHz at nearly 400 mA which increases in frequency and decreases in amplitude as the beam current decays.

We recognized this as possibly being a form of synchrotron oscillations known as the Robinson mode that could be driven by broadband noise in the RF system. By measuring the noise at various points in the RF system, we determined that the dominant source was phase noise in the 500 MHz master oscillator. The details of beam motion driven by phase noise are discussed elsewhere.[4]

In order to further demonstrate the effect of phase noise on the IR beamline, we deliberately excited the cavity by modulating the cavity phase with white noise and measured the response as a function of beam current as shown in Fig. 5a. Shown in Fig. 6a is a calculation of the expected response at the same beam currents, assuming that the motion results from energy oscillations of the beam at the source point.

To find the spectrum of beam motion driven by the MO phase noise, we computed the product of the MO phase noise determined from catalog values with the transfer function computed in Fig. 6a. This is shown in Fig. 6b. This has the same characteristic shape as the measured noise in Fig. 4. Replacement of the existing of the existing MO by a lower noise model reduced this motion by a factor of 5.

The net result of the reduction in phase noise can be observed in Fig. 7, which shows several spectral scans taken before and after the MO phase noise was reduced.

Although we succesfully identified the source of the noise and reduced it, we still did not understand how the beam motion created a signal in the interferometer. To further study this, we measured the beam motion driven by the noisy MO at very low beam current, where we could independently determine the amplitude of synchrotron oscillations and thus the amplitude of energy oscillations at the horizontally dispersive IR source point. Shown in Fig. 8 is a plot of the FTIR noise at low current for the old and new MO. We independently determined that

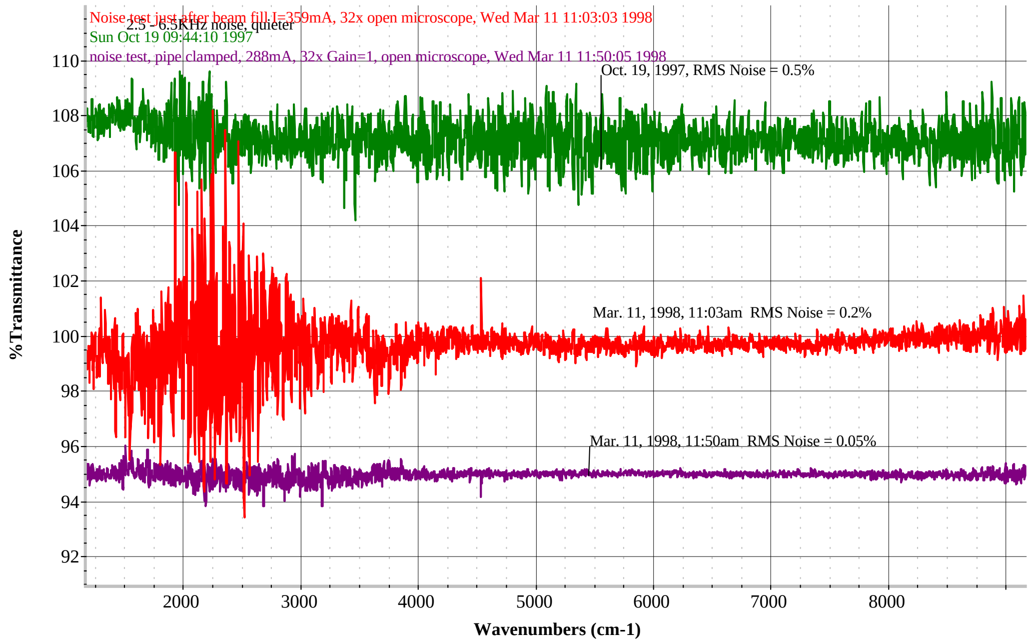

Figure 3. Comparison of FTIR spectra before and after reductions in low frequency noise sources. The increase in noise at the low end of the spectrum is discussed in the text.

the amplitude of beam energy oscillations was 2.8e-5 (relative to the nominal energy), corresponding the horizontal position and angle oscillations of 1.6 μm and 3.8 μrad, respectively.

Our studies also indicated that the intensity of light was varying at the FTIR spectrometer. We considering two possible mechanisms for this: 1) the photon beam is aperture-limited and is modulated by transverse electron beam motion and 2) the energy oscillations create varying intensities of synchrotron light in the fixed magnetic field of the bend magnet. We are currently planning experiments to study this further.

5. CONCLUSIONS

Phase noise in the RF master oscillator has been identified as one of the dominant sources of noise in the ALS infrared beamline. The problem has been substantially reduced by replacing the MO with a lower noise source. Interferometric measurements of synchrotron radiation are very sensitive to beam motion and may be used as a sensitive beam diagnostic. The means by which the noise is observed at the ALS is still under investigation. We would like to thank H. Zyngier for many useful discussions.

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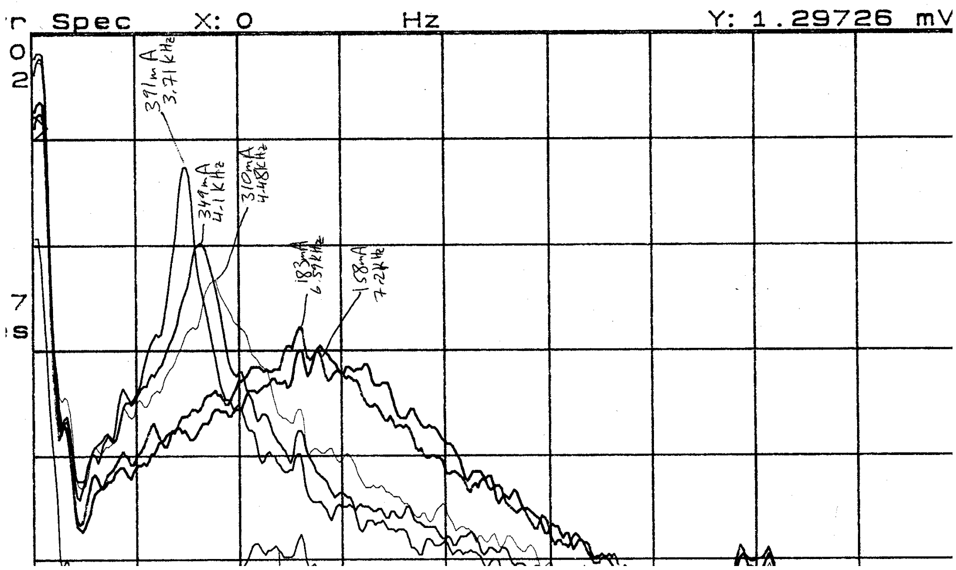

Figure 4. Noise measured in the FTIR as a function of current. The highest peak was recorded at a current of 391 mA and the lowest at 158 mA. The frequency axis ranges from 0 to 23 kHz.

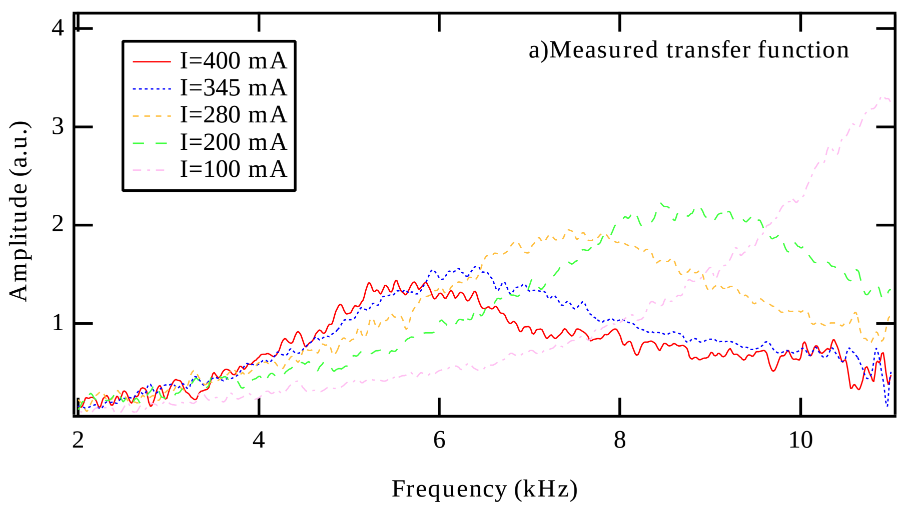

Figure 5. Transfer functions of the FTIR response from exciting the cavity phase at various beam currents.

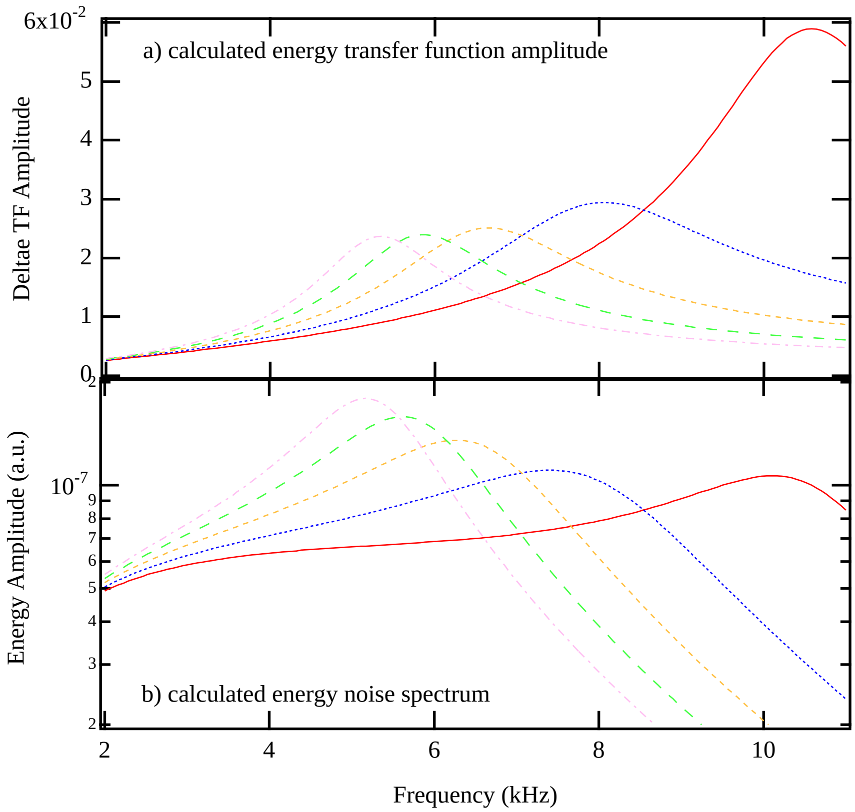

Figure 6. a) Calculated amplitude of the transfer function. This compares well with the measured values in Fig. 3. b) Calculated noise spectrum using the spectrum of MO phase noise and the calculated beam energy transfer function. This shows qualitative agreement with the measured noise in Fig. 2.

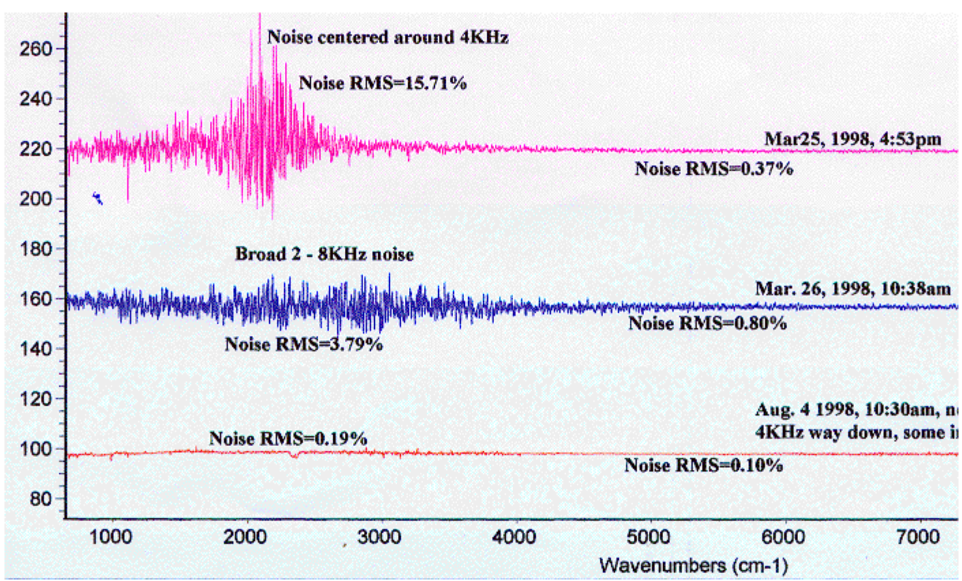

Figure 7. Three IR spectra showing the effects of the MO phase noise. The upper two traces were taken with the old MO, the bottom trace with the new MO.

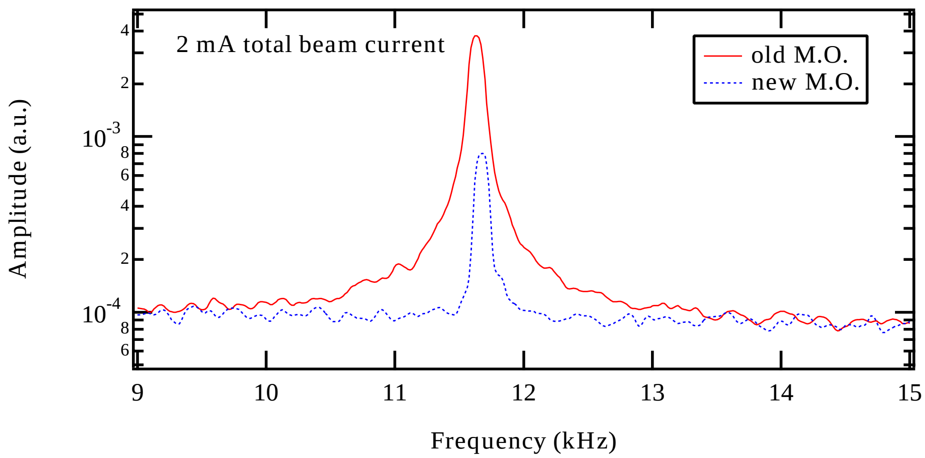

Figure 8. Motion driven by MO phase noise at low beam current for two MO sources. The reduction is equal to the reduction in the phase noise.